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Contributed paper

SRF cryostat dynamics at the Canadian Light Source

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This work includes the creation of a computer model of the superconducting radio frequency cryostat located at the Canadian Light Source (CLS) in Saskatoon, Canada. This cryostat requires careful pressure and level modulation to ensure proper radio frequency control. A detailed mathematical model of the cryostat is generated based on gas and liquid mass balances for a boiling vessel, along with pressure–volume–temperature relations. Model results are compared with experimental data taken from the actual cryostat at the CLS to determine the accuracy of the simulation. Finally, cryostat performance is explored using the model, and it is demonstrated that there are no significant advantages in pressure modulation when reducing the level operating point, and in fact a reduction in operating level slightly increases the maximum value of pressure spikes due to heat loading.

1. Introduction

The superconducting radio frequency (SRF) cavity in the storage ring at the Canadian Light Source (CLS) efficiently replenishes energy lost by the electron beam as the beam emits photon radiation. To achieve superconductivity, the SRF cavity is immersed in a 4.5 K liquid helium (LHe) bath, with LHe supplied by a cryogenic plant. The CLS desires a computer simulator of this cryosystem, to answer questions about system performance and control.

An integral component of the system is the 502 L LHe cryostat, which contains the SRF cavity. In this work, a dynamic model of the cryostat is developed and implemented in a MATLAB^{TM} simulation, which can then be run for a variety of conditions. Simulation results are compared with measured data to determine the validity of the model. The model is then used to examine cryostat behaviour under a specific set of conditions.

2. The physical plant

Figure 1 describes the cryostat at the CLS.

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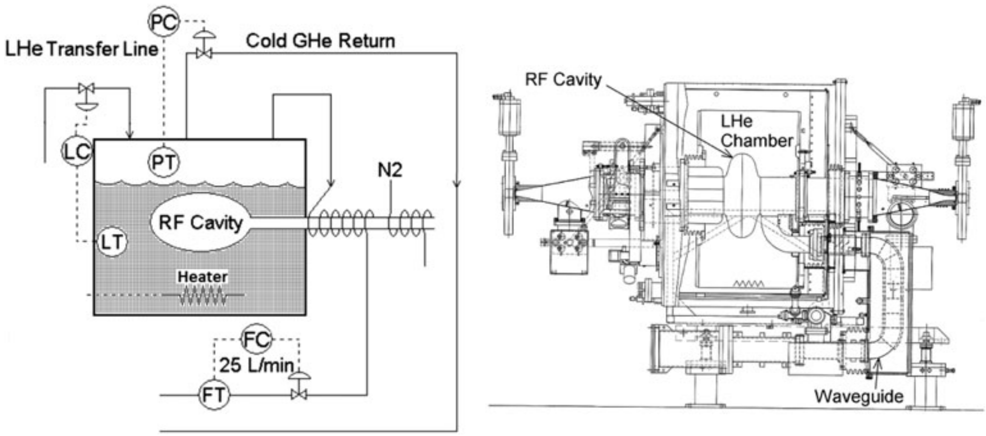

FIGURE 1. CLS cryostat schematic (left) and scale drawing (right).

Cryostat level is controlled by modulating LHe flow from a dewar with a proportional-integral (PI) driven control valve. There is a heater in the cryostat that can be used to vary the heat load on the vessel. Cryostat pressure control is accomplished using another PI controller to adjust the cold gaseous helium return valve.

3. The model

The cryostat model is based on an analysis presented by Thomas (1999), with the equations reworked to use a pressure formulation in place of the temperature formulation used by Thomas (1999). This model is described in detail by Regier, Pieper & Matias (2010). Conservation equations for liquid mass, gas mass, energy and volume are combined with an equation relating the gas law to the pressure–temperature relationship for a boiling liquid. The fluid properties required to solve these five base equations were related to pressure by fitting curves to helium properties data taken from the National Institute of Standards and Technology (Lemmon, McLinden & Friend 2008).

For stand-alone operation of the vessel simulation, discrete PI controllers were used to drive the inlet and outlet mass flow rates directly. The static heat load on the cryostat was determined separately using two different methods. One method indicated that static heat load varies with applied heat, while the other suggested a constant static load of 37.2 W.

The model was validated by comparing level data during filling with the cryostat simulator's response to the same conditions, and also by applying cryostat heater power to the simulator in steps, regulating the level and pressure in the simulator and comparing the corresponding gas outlet mass flow rates computed by the simulator with actual measured gas outlet flows.

4. Pressure control

Once validated, the simulator was used to determine whether a decrease in level would result in better pressure control. The theory behind this idea is that a larger gas cap in the top portion of the cryostat may act as a spring to help moderate the

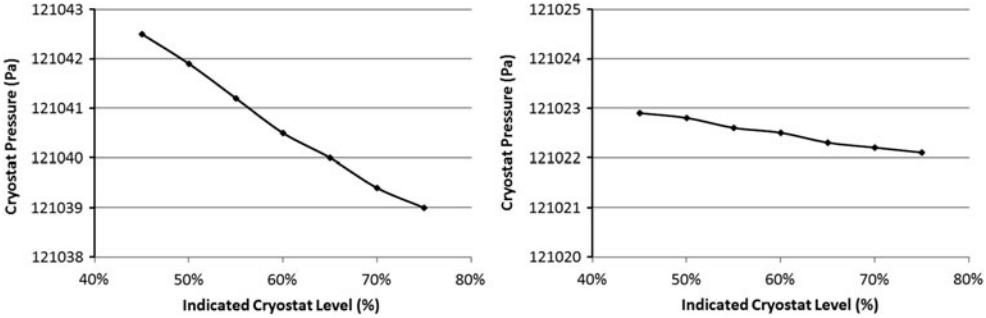

FIGURE 2. Maximum pressure spike for various operating levels for lower pressure control gain (left) and for higher pressure control gains (right).

effects of sudden pressure changes. A 30 W, 3 s heat spike was introduced to the cryostat simulator for levels of 45, 50, 55, 60, 65, 70 and 75% (indicated values). Pressure was modulated at 1.21 bar (121 000 Pa) for all cases using the above-mentioned PI controller.

The left side of figure 2 shows the maximum pressure measured for each of the above cases. The right side indicates the maximum pressure when the pressure PI control gains were increased by a factor of 5, which resulted in about 13% more flow out of the cryostat at the maximum flow rate. Figure 2 actually shows a slight increase in the magnitude of pressure spikes occurring at lower operating levels and also shows that increasing pressure gains have the potential to reduce the magnitude of pressure spikes.

5. Conclusions

Using mass flow balances and basic physical principles, a simulator was generated to represent an LHe cryostat located at the CLS in Saskatoon, Canada. The simulation was then shown to predict, with reasonable accuracy, the behaviour of the cryostat by comparing simulation results to data collected from actual events. The validated simulator was then used to demonstrate that minimizing the magnitude of pressure spikes in the cryostat could potentially be done by increasing pressure control gains and that reducing cryostat liquid level unexpectedly resulted in a slight increase in the magnitude of pressure spikes.

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